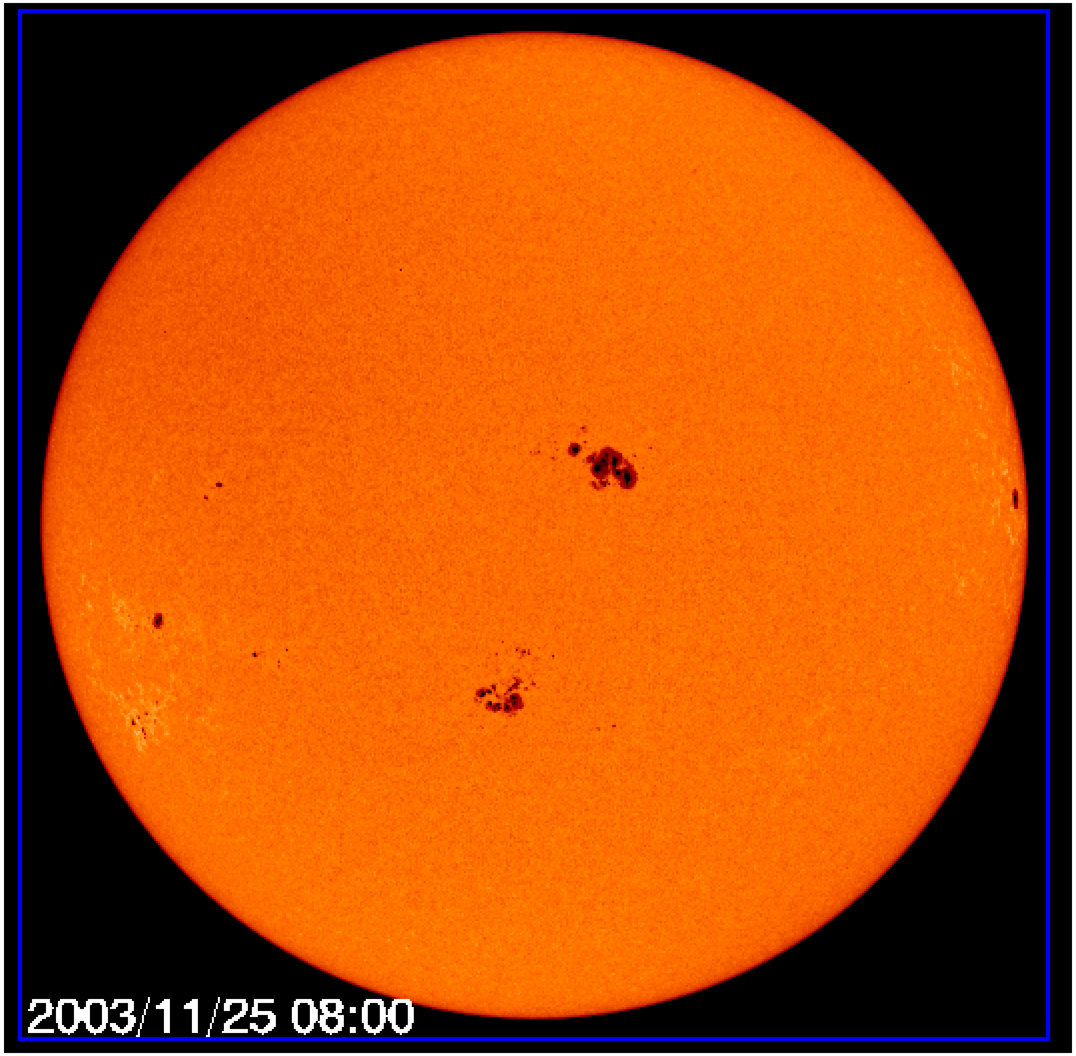
LECTURE SCHEDULE, Revised 11/6/07

Dates	**Topics**	**Reading**
Sep 27	Course Intro, Solar System in Perspective	1
Oct 2, 4	Night Sky, Science of Astronomy	2, 3
Oct 9, 11	Matter and Energy, Newton's Laws and Gravity	4
Oct 16, 18	Light, Telescopes	5, 6
Oct 23, 25	*San Diego fires, no classes*	
Oct 30	Introducing the Solar System	7
Nov 1	Midterm exam	
Nov 6, 8	Solar System Formation, The Sun	8, 14
Nov 13, 15	Planetary Geology, Planetary Atmospheres	9, 10
Nov 20*	Jovian Planets, Rings and Moons	11
Nov 27, 29	Asteroids, Comets, Pluto ; Unique Planet Earth,	12, 13
Dec 4, 6	Life Beyond Earth, Extrasolar Planets	24
Dec 13	Final exam, 8-11am	

***Thanksgiving week.**

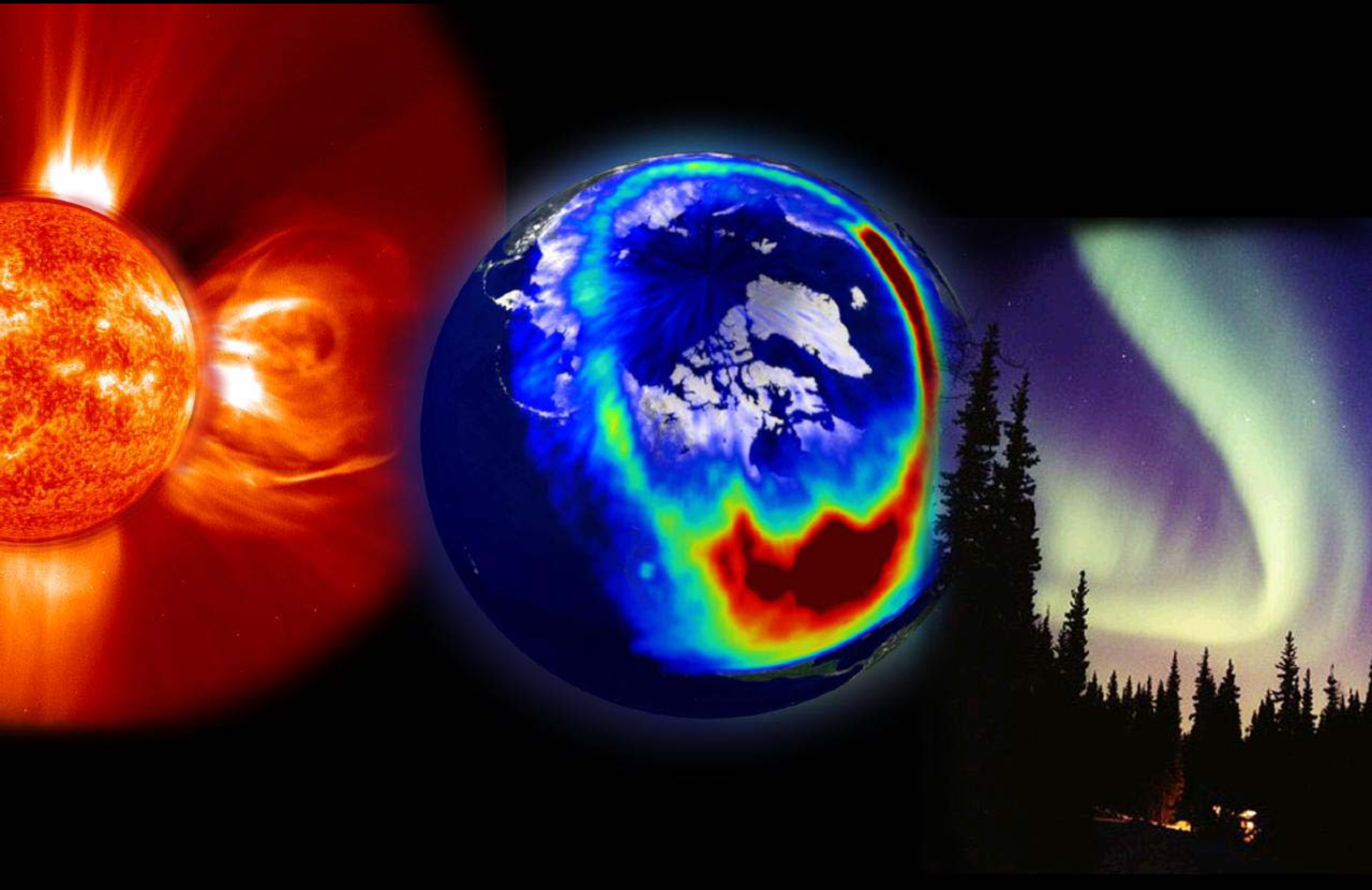
Chapter 14

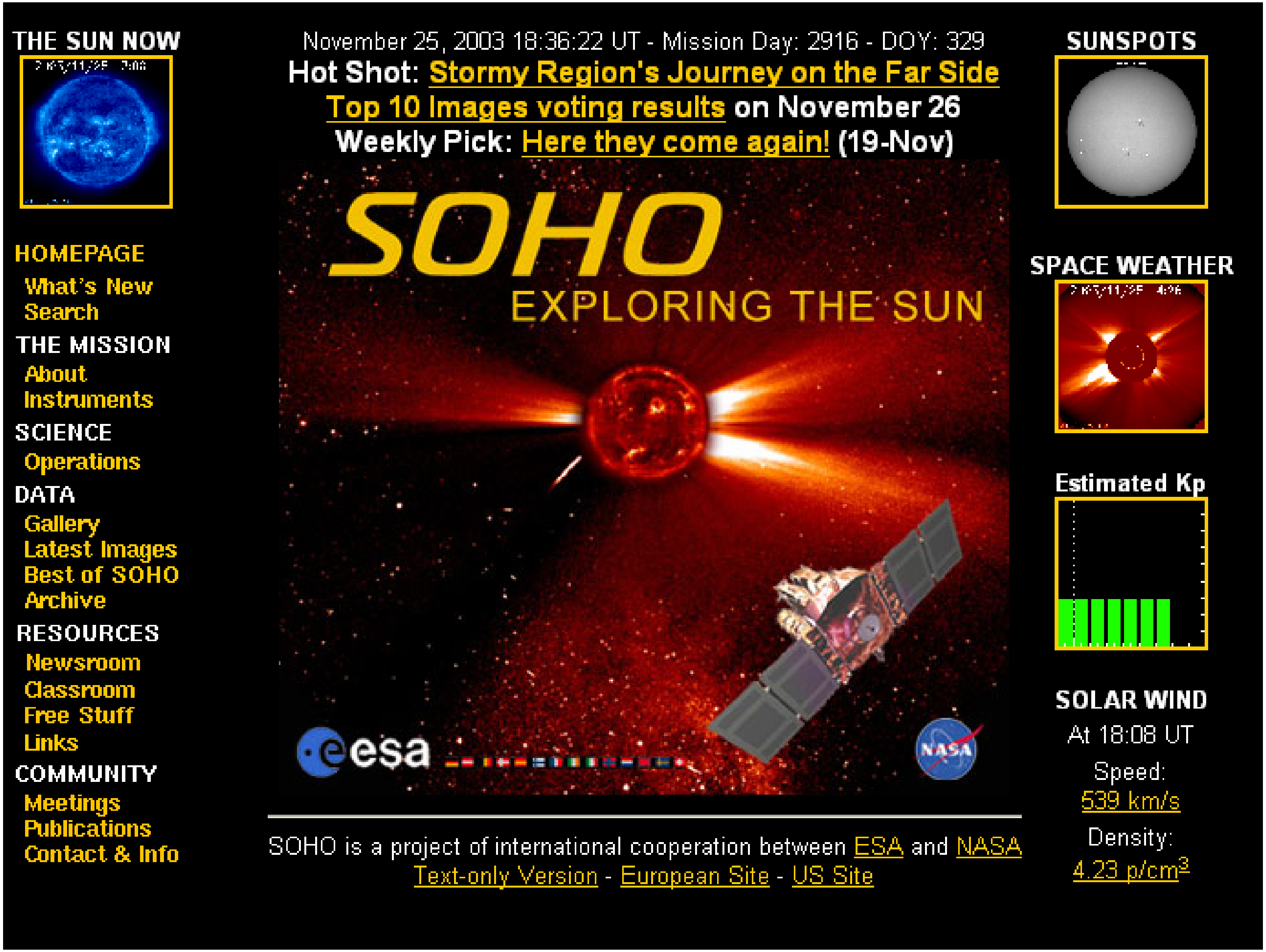


The Sun

http://sohowww.nascom.nasa.gov/

Sun-Earth Connection





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Topics

- Bulk Properties
- Solar Interior
- Solar Atmosphere
- Solar Energy Generation
- Solar Magnetic Activity

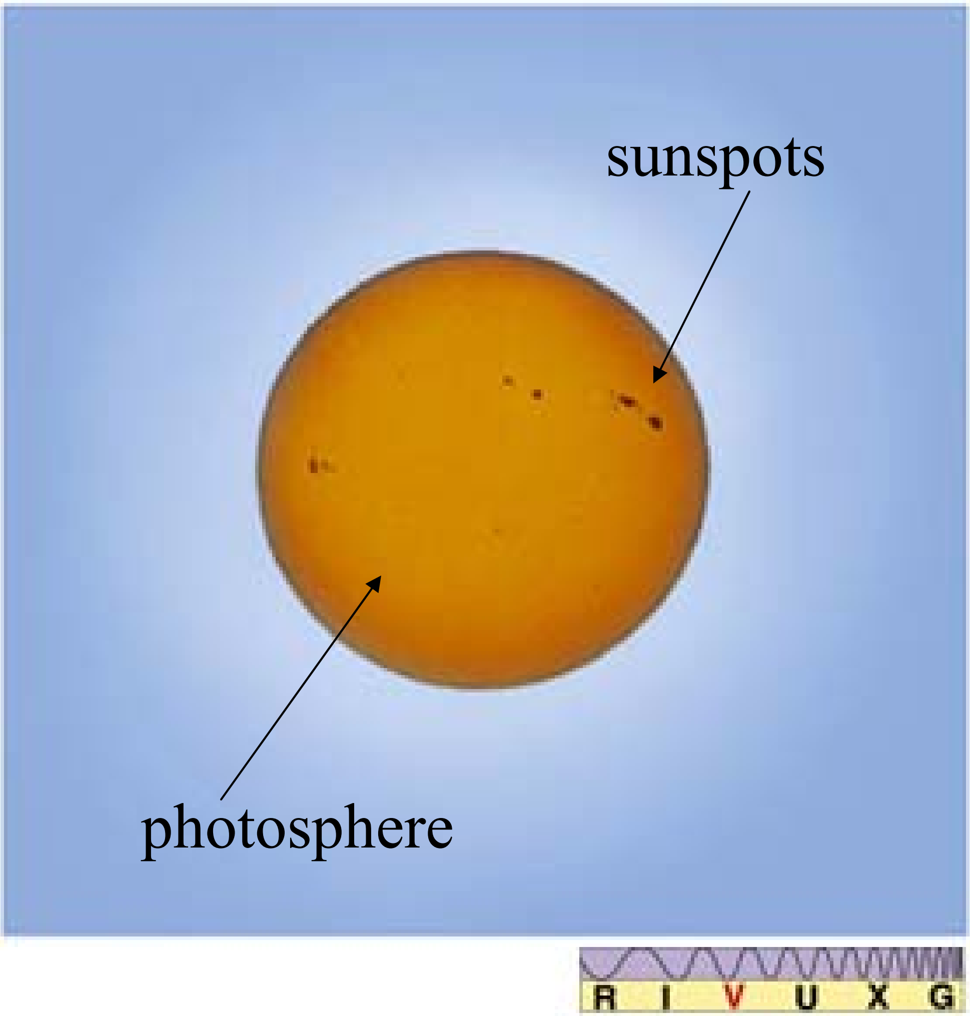
The Sun in Bulk

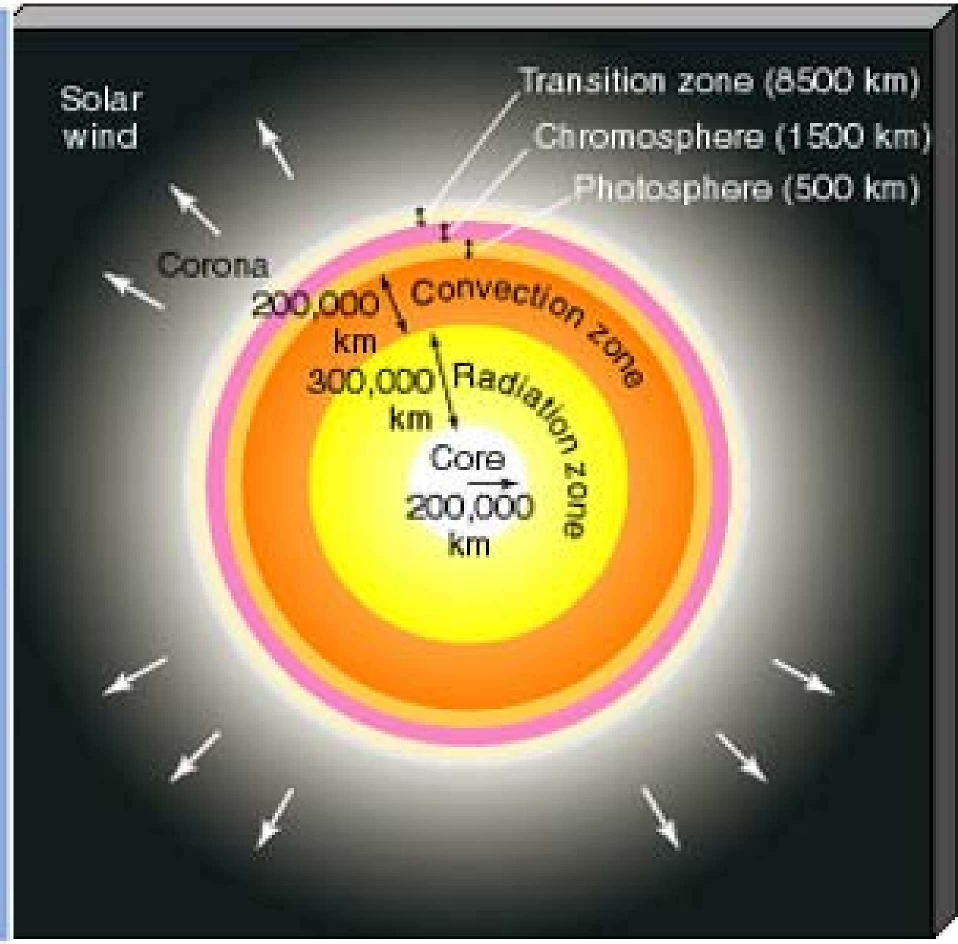
- Nearest and best-studied star in the universe
- 300,000 x closer than Alpha Centauri
- corner stone for our understanding of stars

TABLE 9.1 Some Solar Properties

RADIUS	**696,000 KM**
Mass	1.99×10^{30} kg
Average density	1410 kg/m^3
Rotation period	24.9 days (equator); 29.8 days (poles)
Surface temperature	5780 K
Luminosity	3.86×10^{26} W

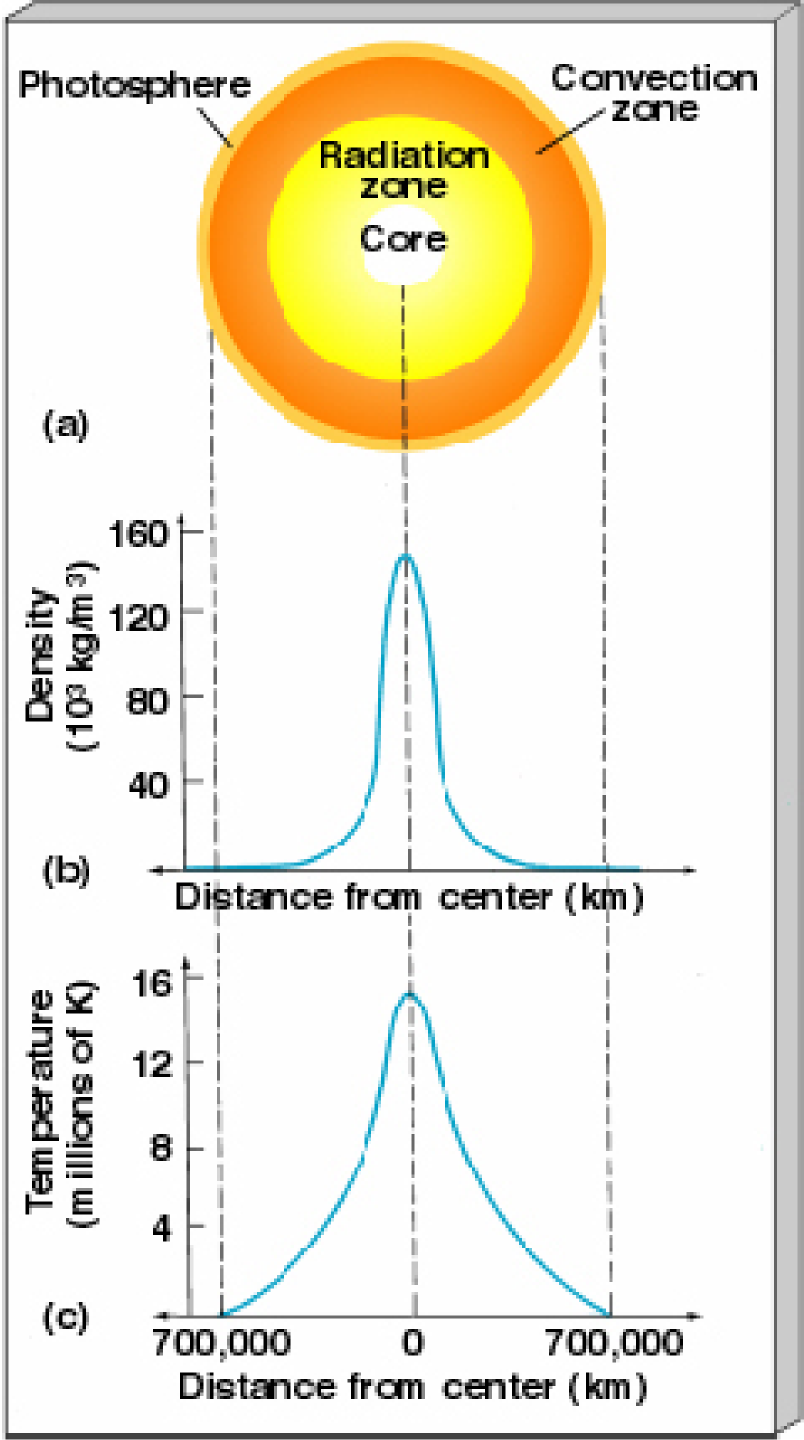
Solar Structure





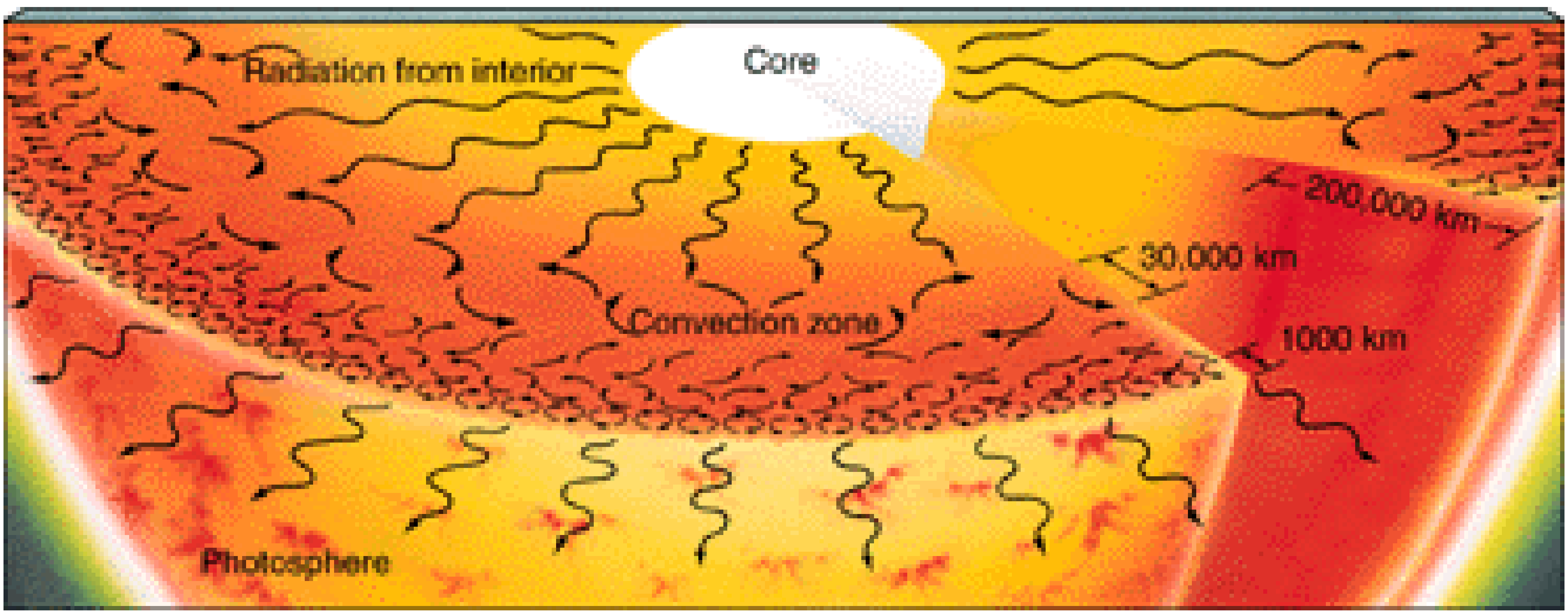
Solar Interior

- Density and temperature profiles from mathematical models (verified by helioseismology data)
- central density=20x density of iron
- central temperature =15 million degrees Kelvin

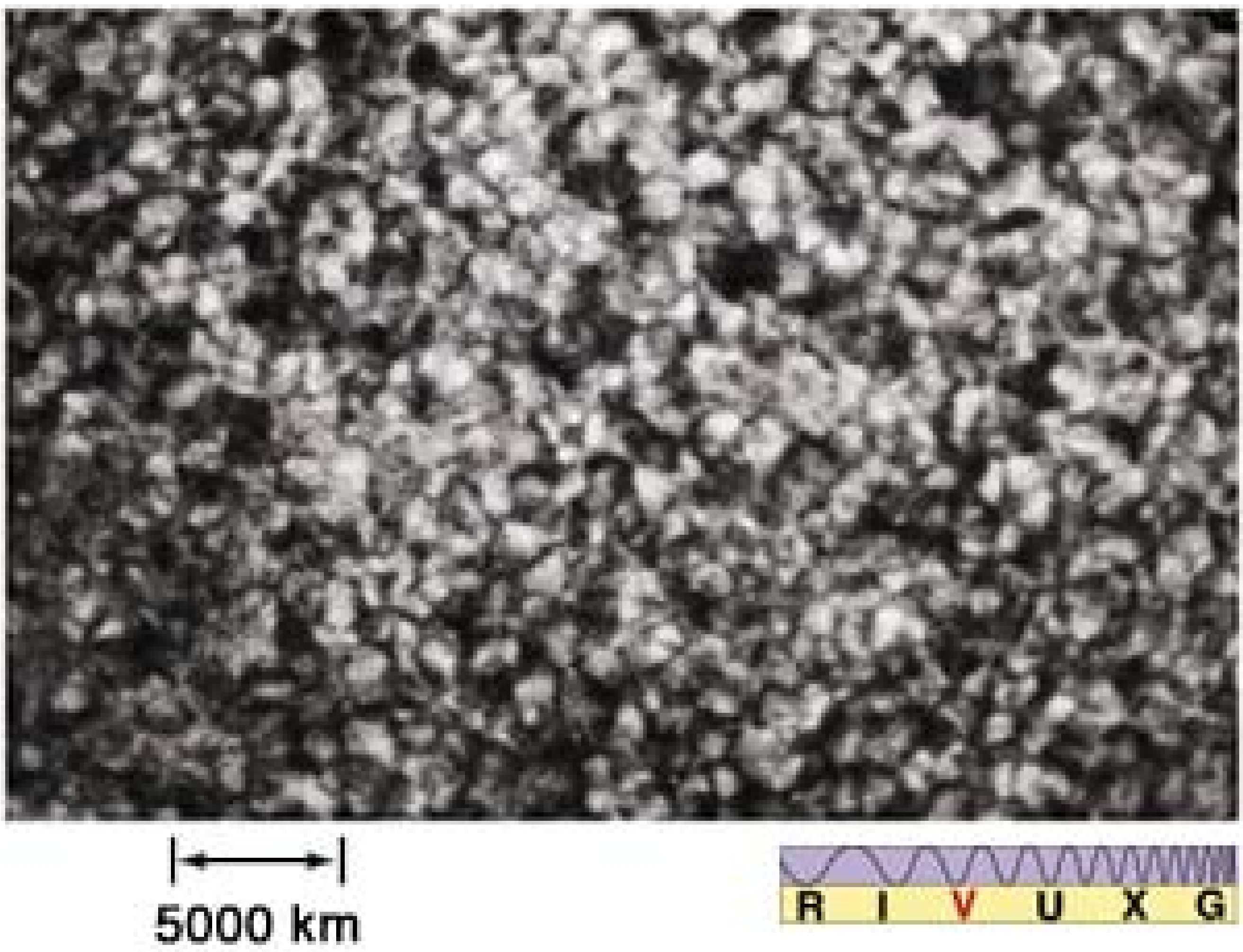


Energy Transport

- Energy generated by *nuclear fusion* in core
- energy transported outward by *radiation* near core, and then *convection* near surface



Evidence of Solar Convection-
Solar Granulation



Solar Atmosphere: The Photosphere

- “bright sphere”
- composition determined by detailed spectroscopic analysis
- thousands of absorption lines reveal presence of 67 chemical elements

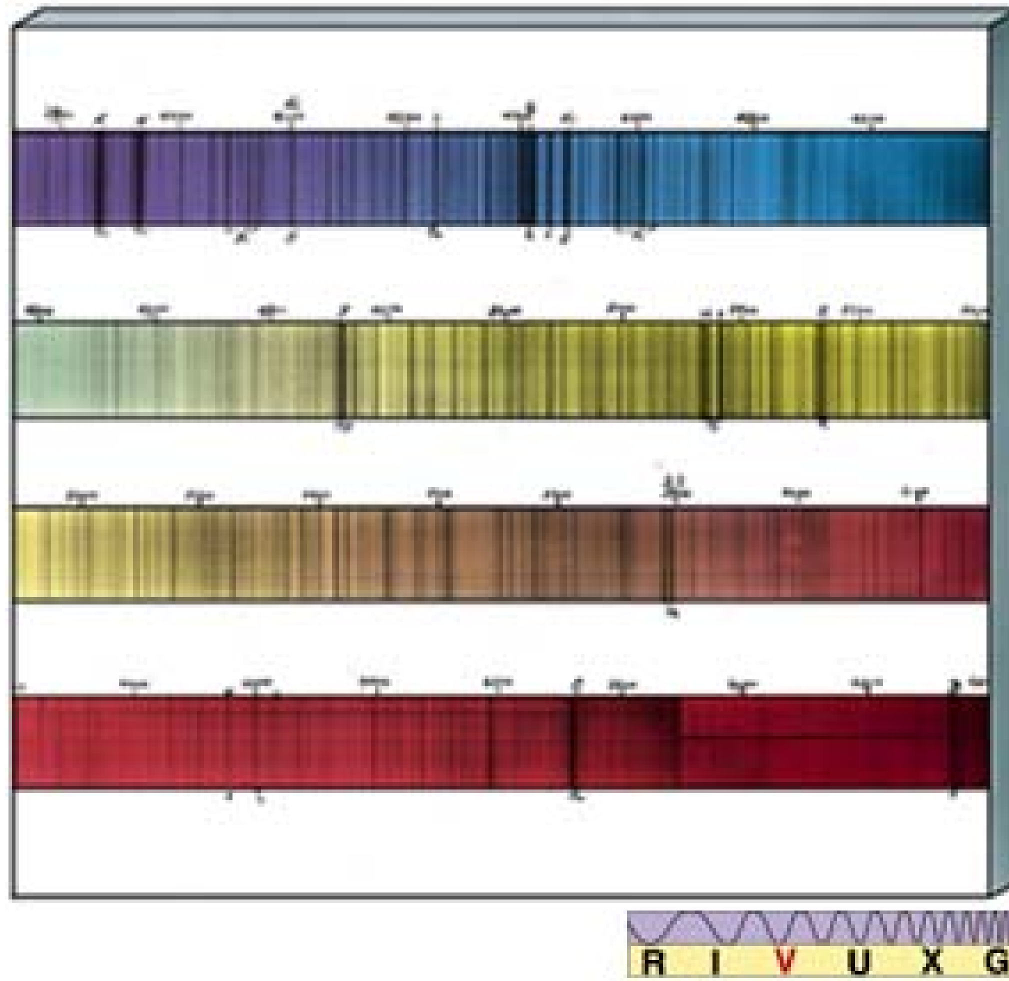


TABLE 9.2 The Composition of the Sun

ELEMENT	PERCENTAGE OF TOTAL NUMBER OF ATOMS	PECENTAGE OF TOTAL MASS
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.0030	0.14
Sulfur	0.0015	0.040

Solar Atmosphere: The Chromosphere

- "colored sphere"
- visible only during total solar eclipse
- pink-red color due to emission lines of Hydrogen
- dynamic features: flares and spicules

Solar Spicules

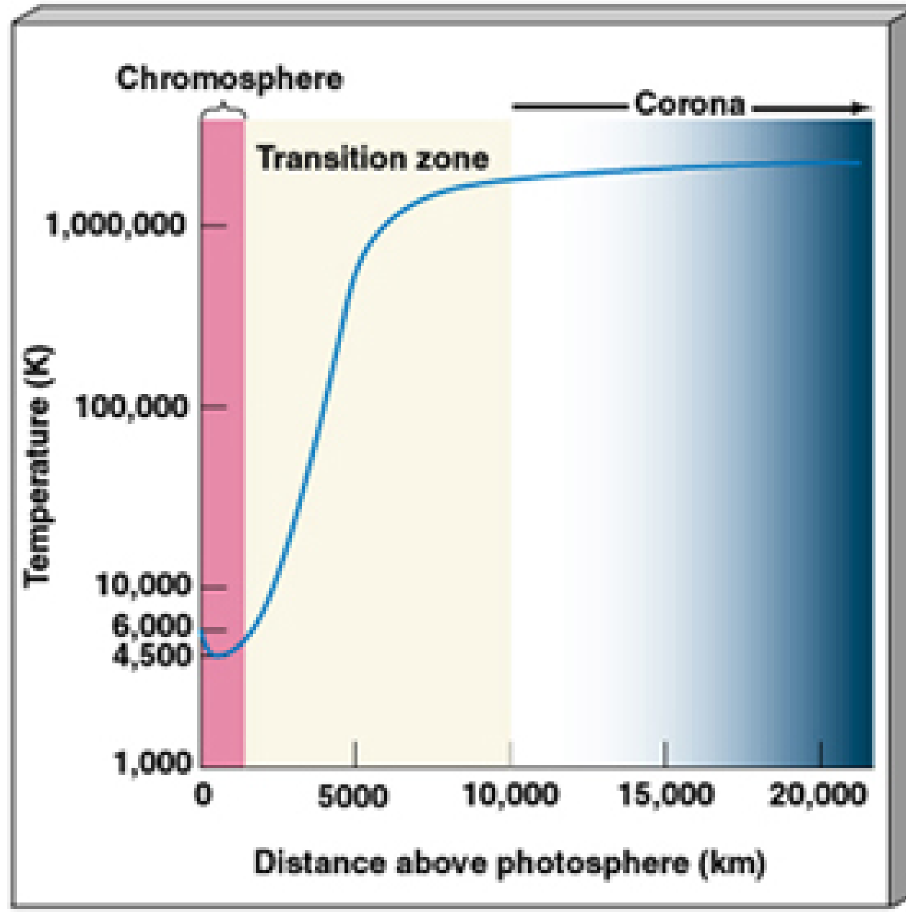
- Jets of gas squirted out of photosphere by convective motions
- appear dark when seen in absorption against photosphere
- looks like "grass growing up between flagstone pavers"

Solar Atmosphere: The Corona

- "the crown"
- outer-most part of solar atmosphere
- milky-white; visible only during total solar eclipse
- spectrum: continuous + emission lines
- temperature ~ million degrees K

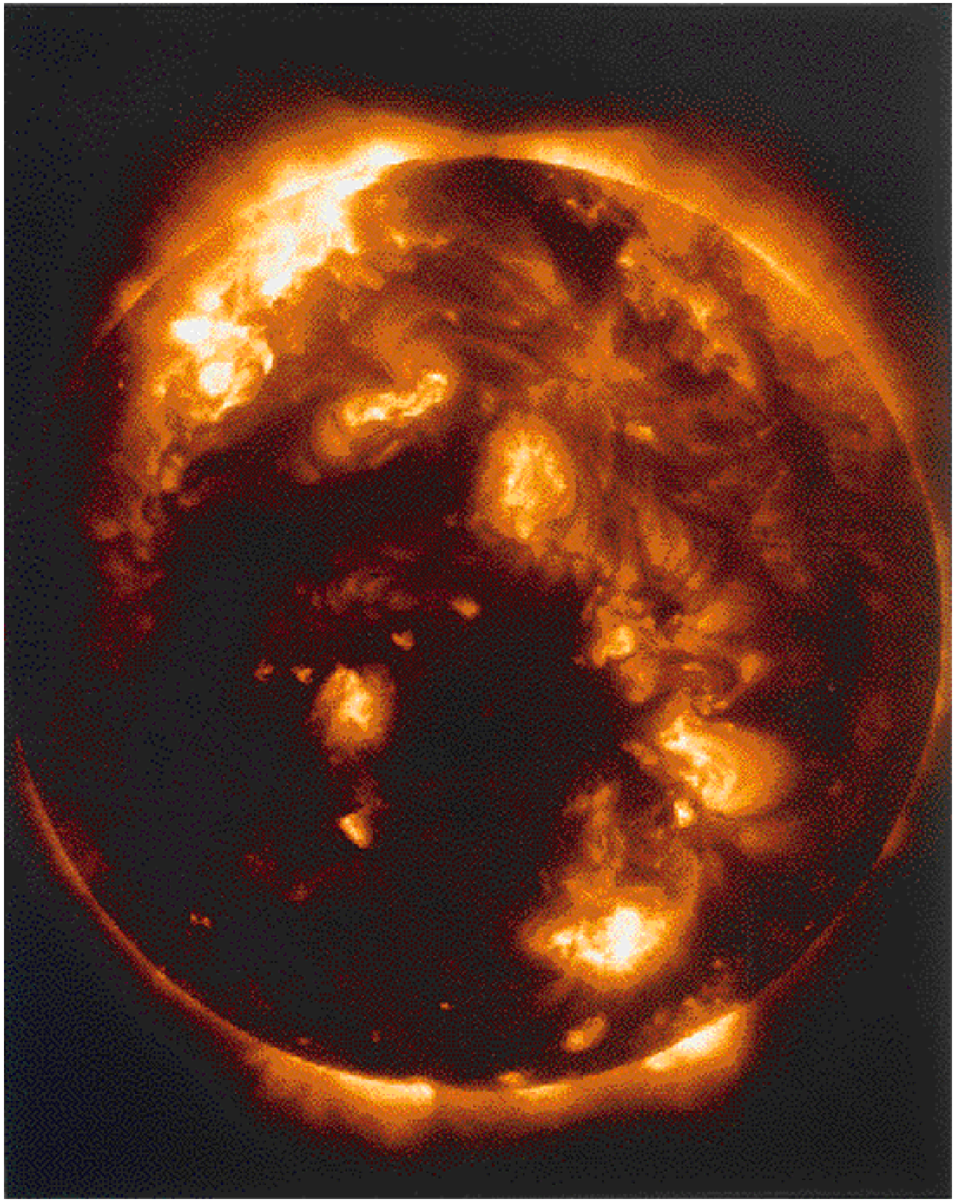
Solar Atmospheric Temperature

- *temperature minimum* in chromosphere (4500K @ h=500 km)
- steep rise in *transition region* to ~10^6 K (500 km < h < 5000 km)
- *heating mechanism* not completely understood; thought to be related to *magnetic activity*



The Sun in X-rays

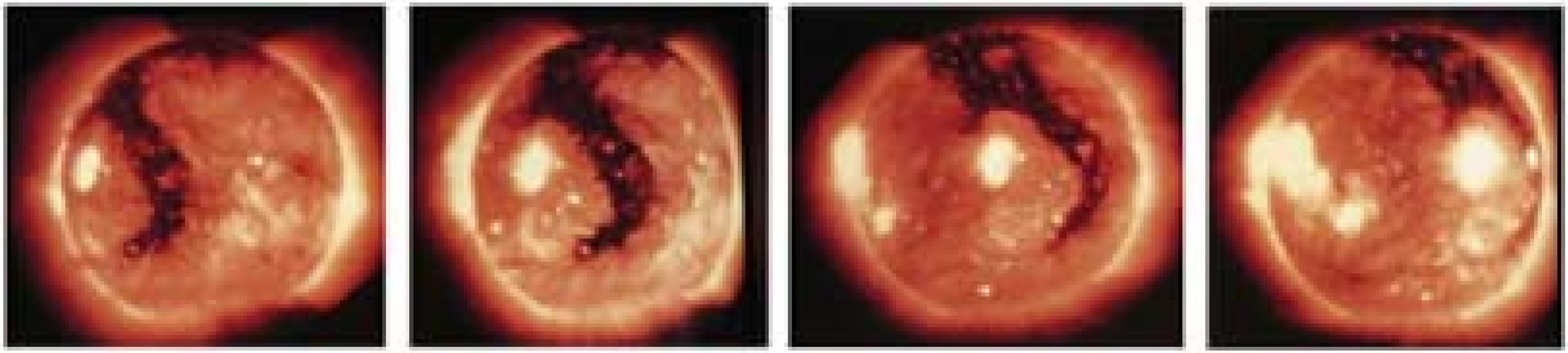
- million degree gas emits in X-ray
- X-ray telescopes best way to study corona
- bright regions
  - high density gas
- dark regions
  - low density gas
- patchy distribution governed by structure of Sun’s magnetic field



Yokoh Solar Observatory

Coronal Holes

- dark regions seen in x-ray are *coronal holes*
- source regions of *solar wind*
- correspond to regions where magnetic field lines are open to interplanetary space

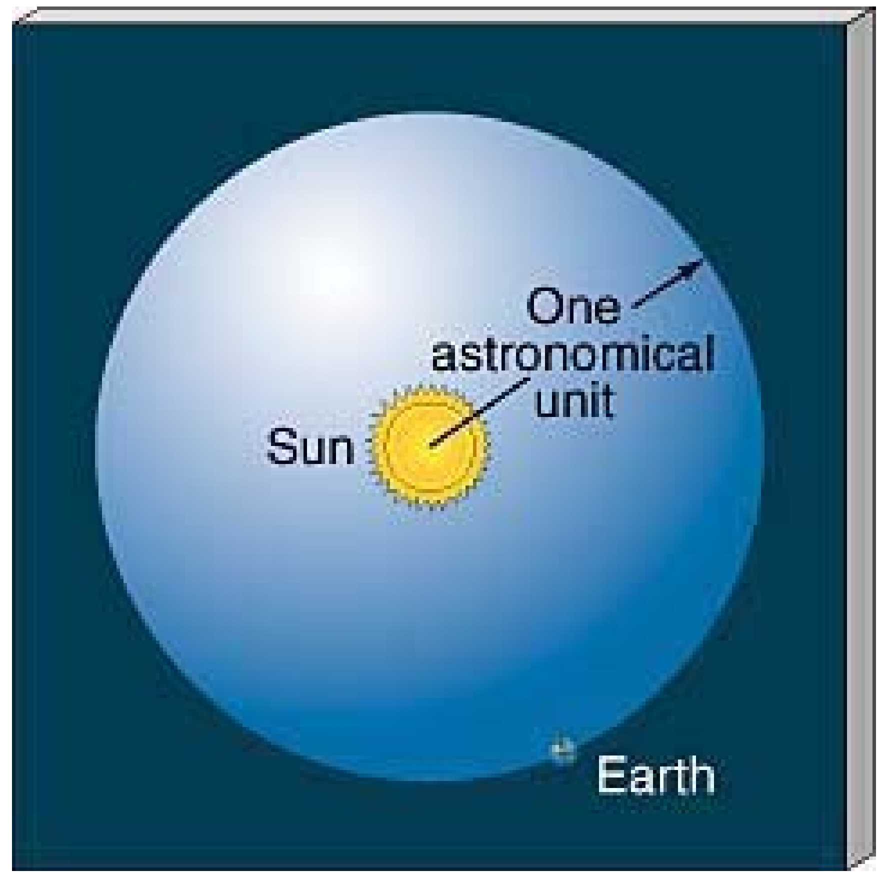


Coronal Holes: Origin of Solar Wind

http://www.lmsal.com/SXT/

How much energy does the Sun put out?

- We can measure intensity of sunlight at the Earth
- *Solar constant*=1400 Watts/meter^2
- *Solar luminosity*=1400 W/m^2 x area of surface of sphere @ 1 AU =4x10^{26} W



How the Sun Generates Energy

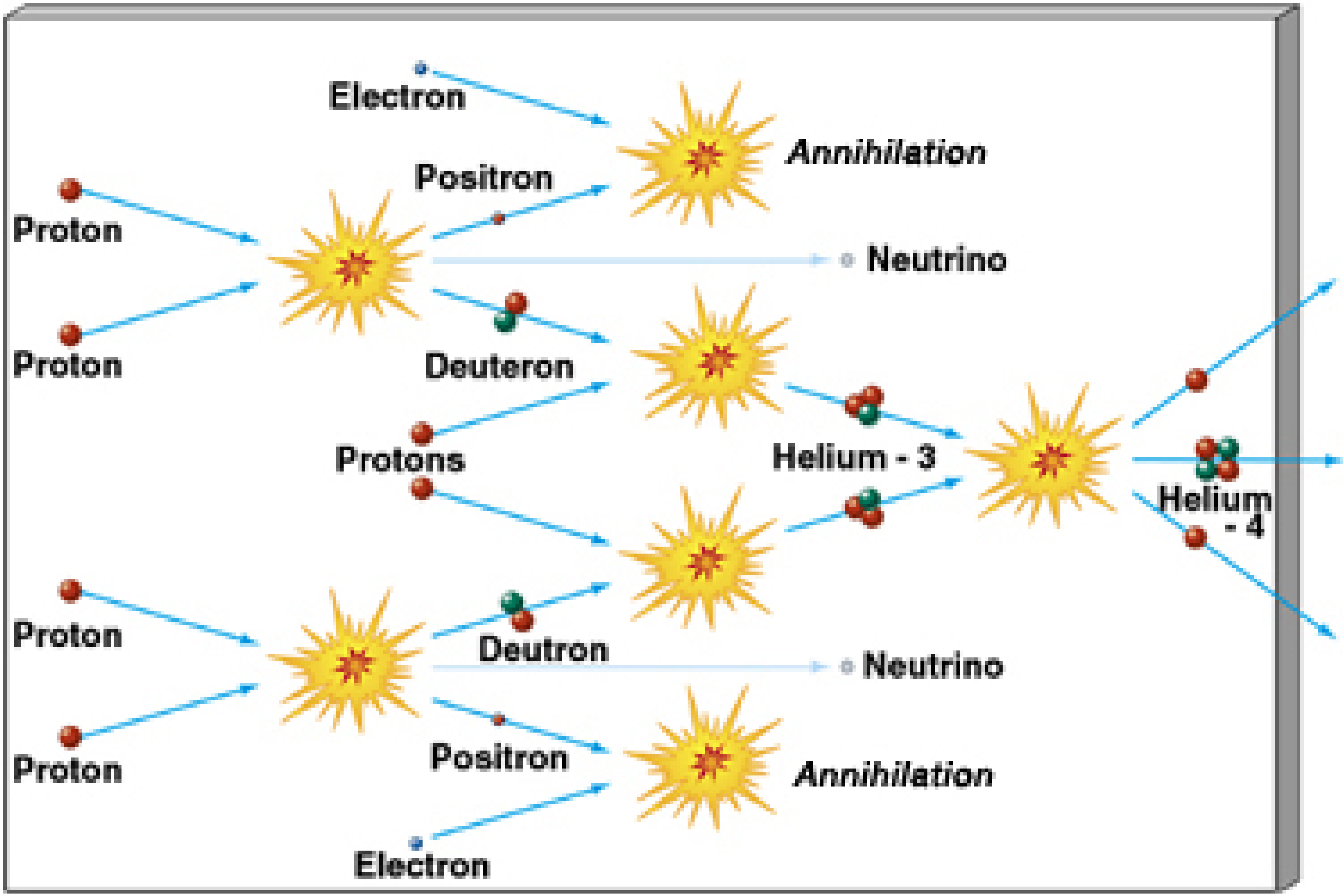
- Converts "burns" hydrogen atoms into helium atoms in its core via *nuclear fusion*
- schematically:

$$\text{nucleus 1} + \text{nucleus 2} \rightarrow \text{nucleus 3} + \text{energy}$$

$$\begin{array}{cccc} m_1 & m_2 & m_3 & E \\ m_1 c^2 & m_2 c^2 & m_3 c^2 & \end{array}$$

$$E = (m_1 c^2 + m_2 c^2 - m_3 c^2)$$

Proton-Proton Chain



Energy Produced by P-P Chain

- Overall, we have

$$4\ \text{protons} \rightarrow \text{helium-4} + 2\ \text{neutrinos} + \text{energy}$$

$$4\mathrm{m_p} \qquad \mathrm{m_{He\text{-}4}} \qquad 2\mathrm{m}_\upsilon \qquad \mathrm{E}$$

$$4\mathrm{m_p}c^2 \qquad \mathrm{m_{He\text{-}4}}c^2 \qquad 2\mathrm{m}_\upsilon c^2$$

$$\mathrm{E} \approx (4\mathrm{m_p}c^2 - \mathrm{m_{He\text{-}4}}c^2) = 4.3 \times 10^{-12}\ Joules/reaction$$

- How many reactions/second are needed to provide solar luminosity? (hint: 1 Watt=1 Joule/sec)

The Sun's Burn Rate

- Solar luminosity

$$L = 4 \times 10^{26} \text{ Joule/sec}$$

$$\text{reactions/sec} = (\text{Joules/sec})/(\text{Joules/reaction})$$

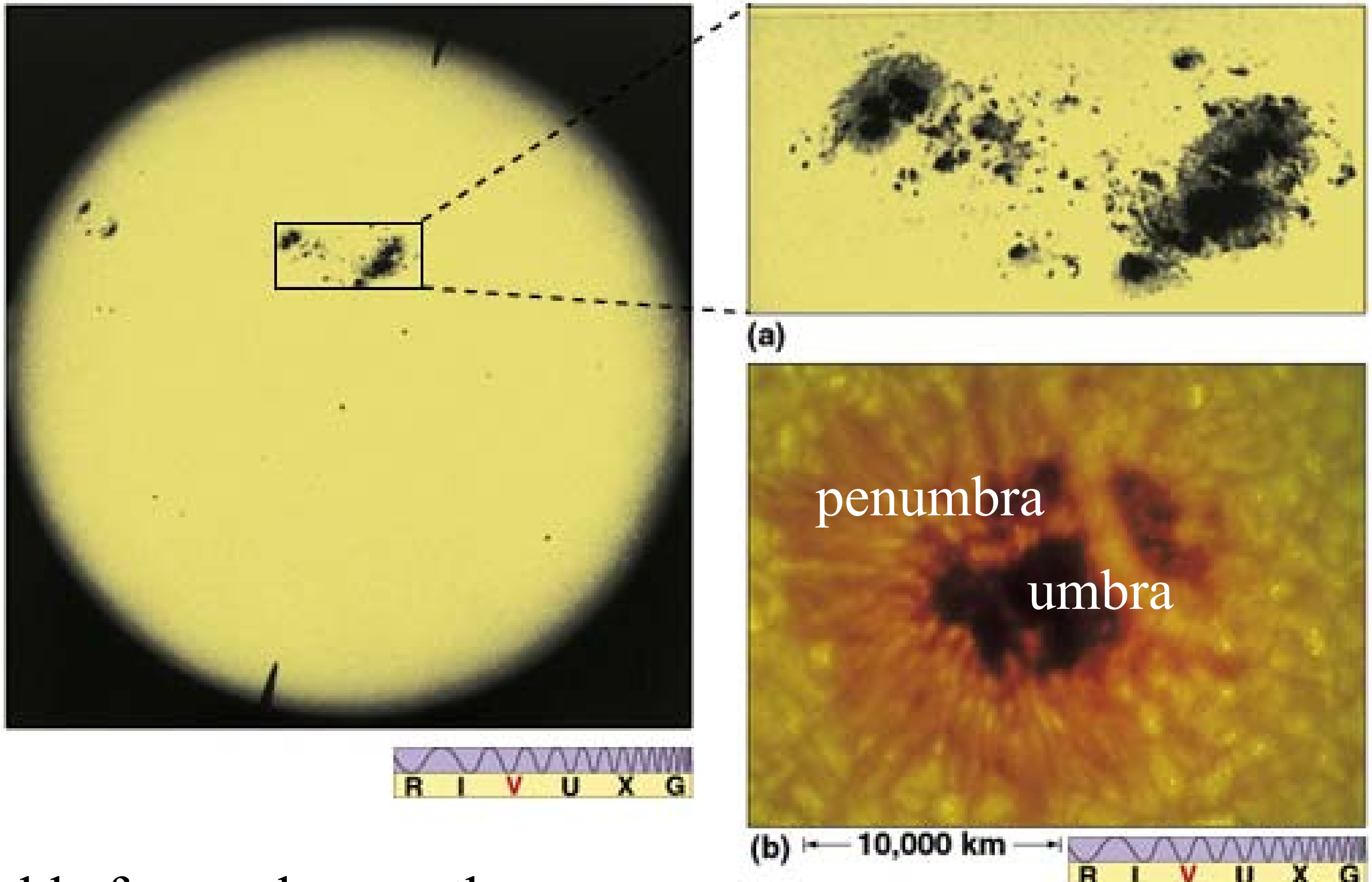
$$= 4 \times 10^{26} / 4.3 \times 10^{-12} \sim 10^{38}$$

- corresponds to 600 million tons/sec of H

Solar Activity

- The Sun exhibits many features (e.g., sunspots, flares, eruptions) which come and go on *day to year timescales*
- All are caused by the Sun's *dynamic magnetic field*, which is generated by internal electrical currents and amplified in the convection zone
- *solar magnetism* is not yet completely understood, but is fascinating in its phenomena
- *space weather* influenced by solar activity

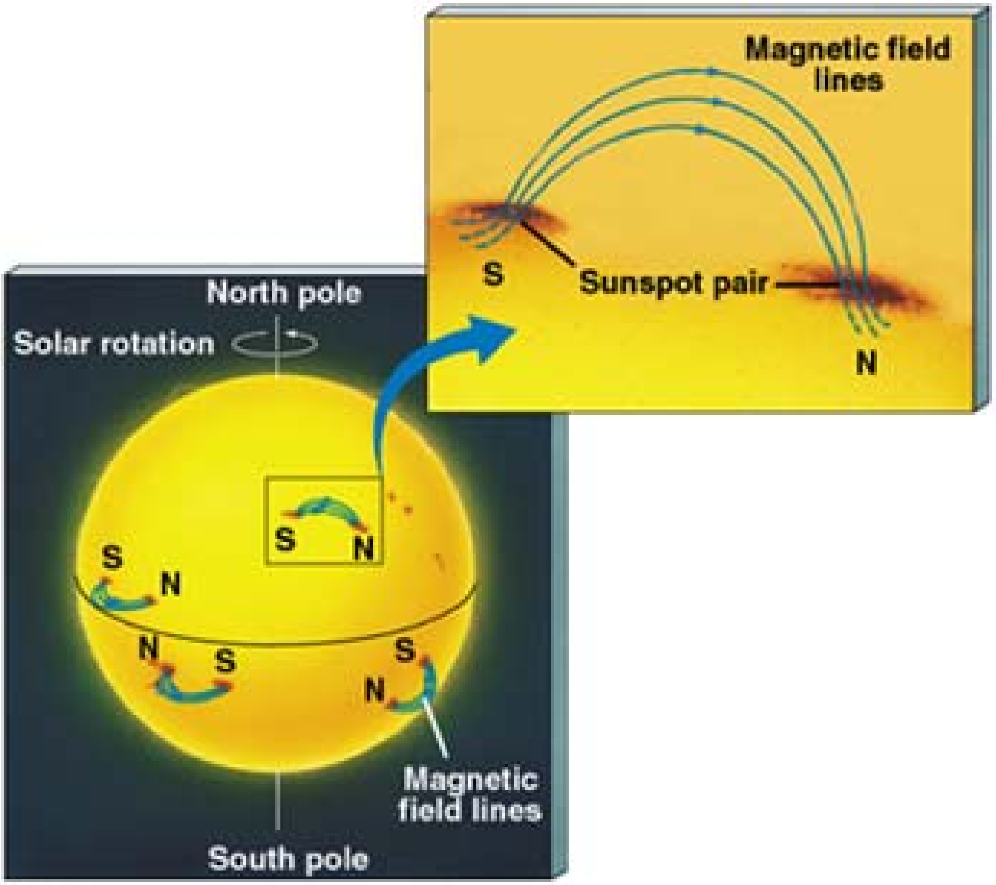
Sunspots



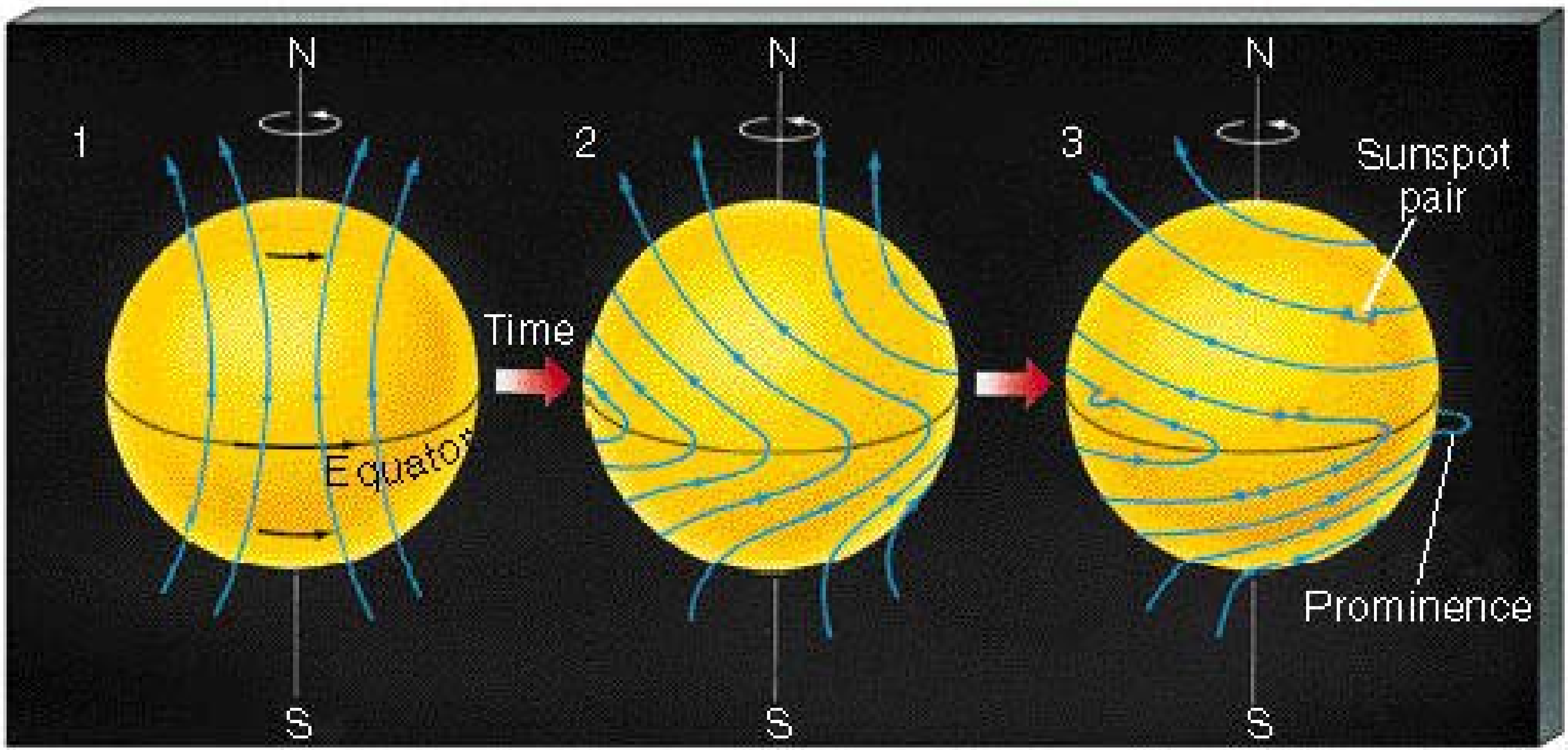
stable for weeks-months

Sunspot Magnetism

- Sunspots always come in pairs
- represent footpoints where magnetic arch pierces photosphere
- pairs have opposite polarity in nothern and southern hemispheres

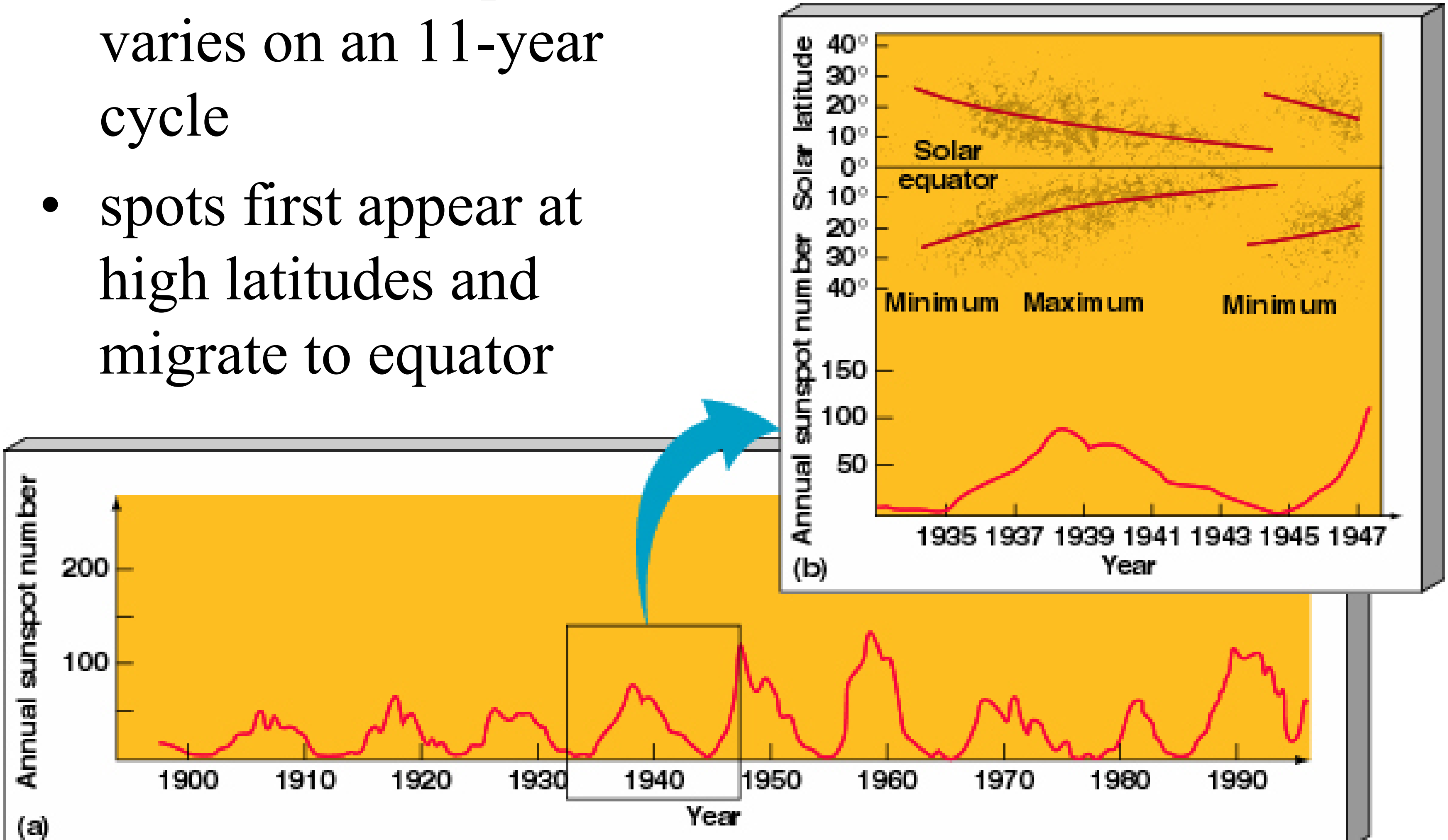


How Sunspots Form



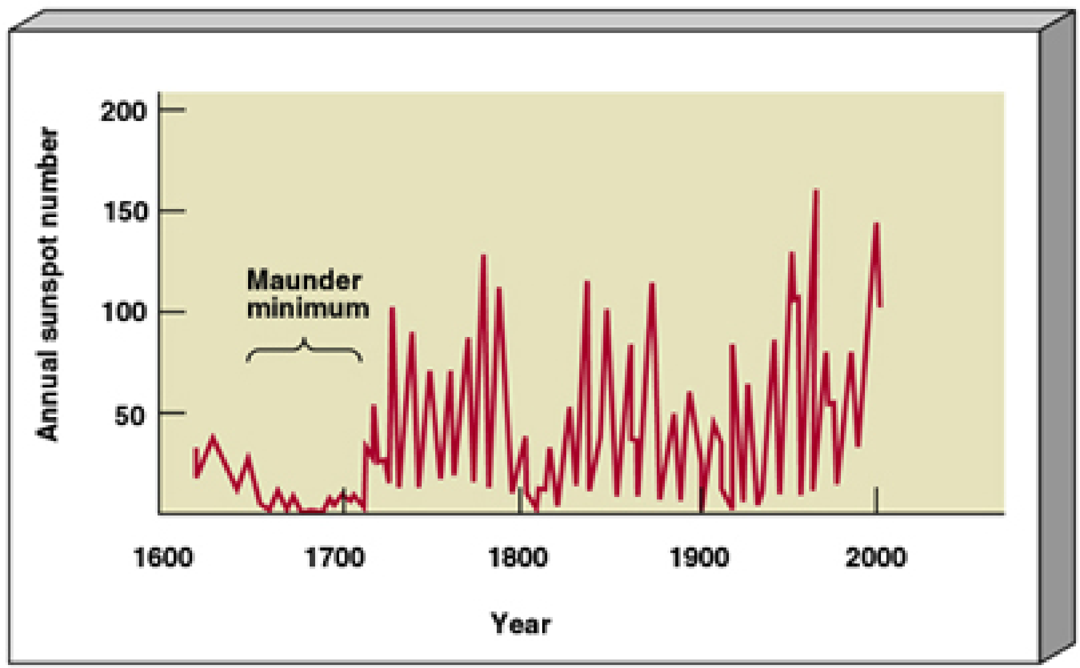
Sunspot Cycle

- number of sunspots varies on an 11-year cycle
- spots first appear at high latitudes and migrate to equator



The Maunder Minimum

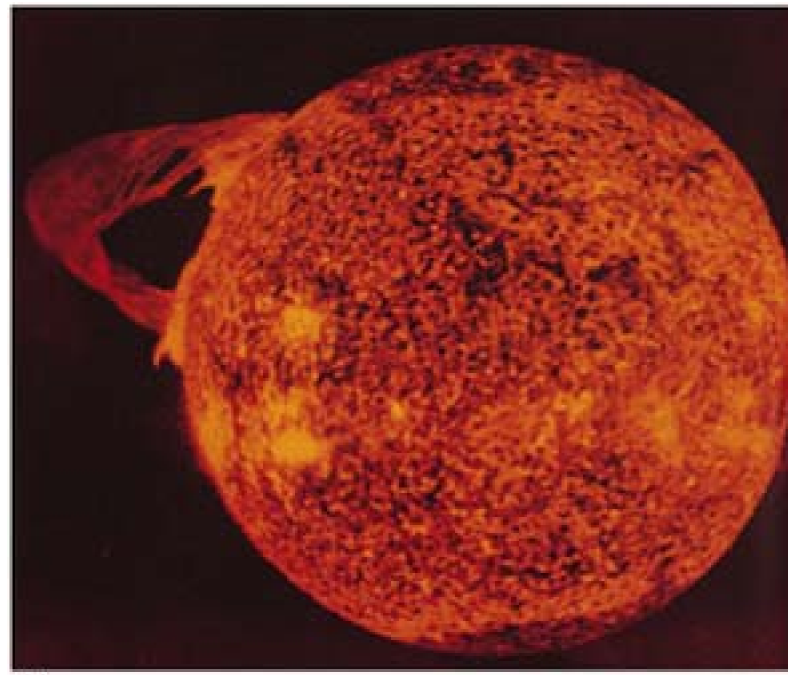
- Period of solar inactivity 1645-1715
- coincident with "Little Ice Age"
- evidence of possible link between solar activity and global warming/cooling



Active Regions

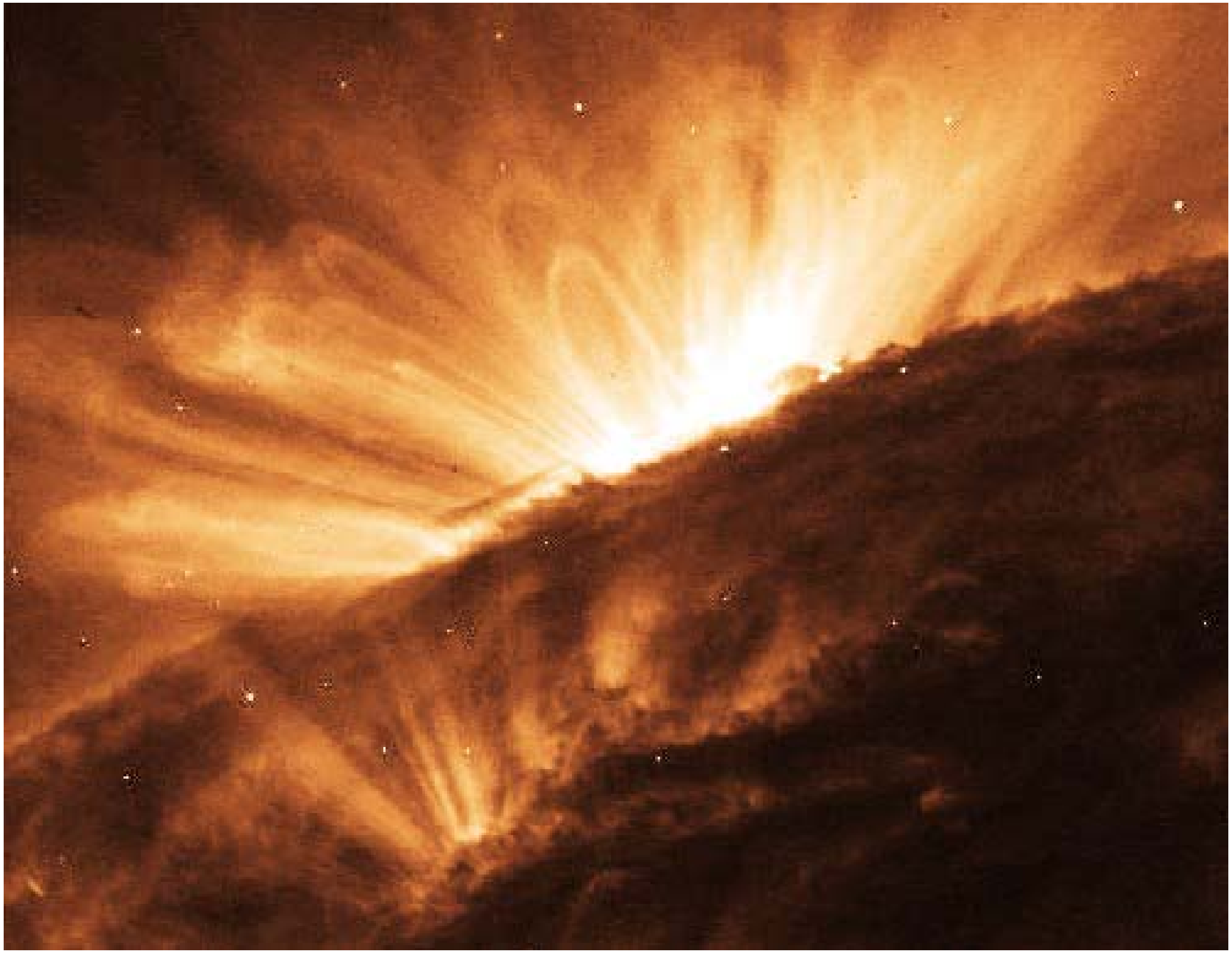
- *Solar prominence*
- magnetic arch which balloons up into the corona
- last for days to weeks

(a)



(b)

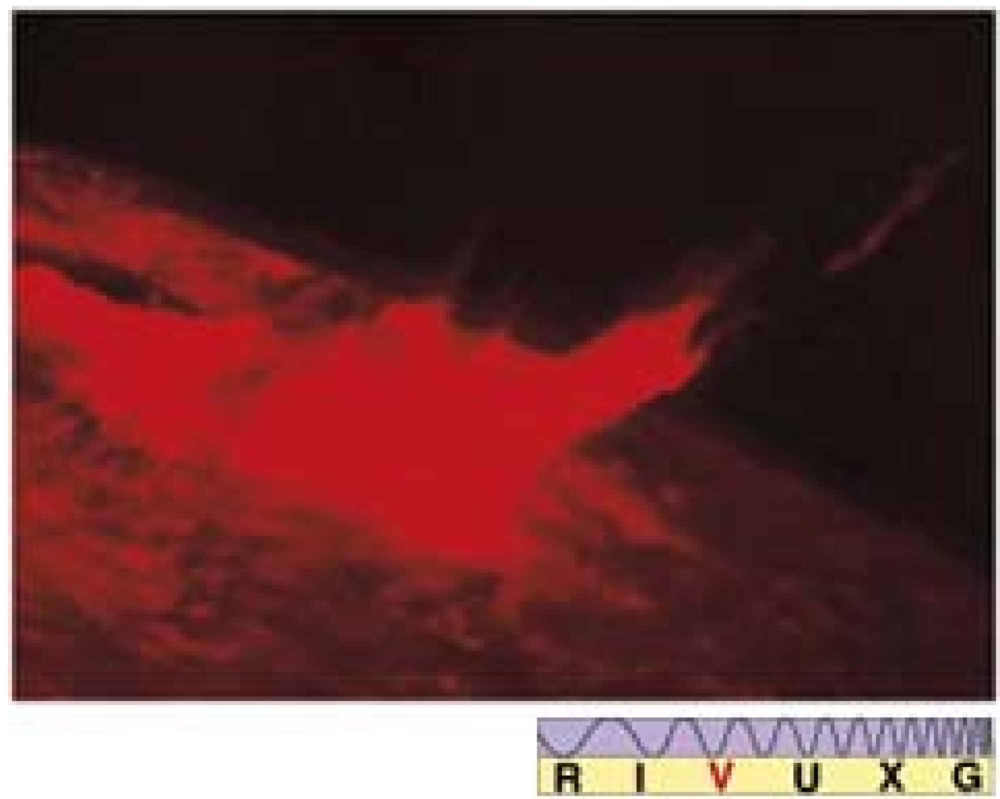
Closeup of Active Region



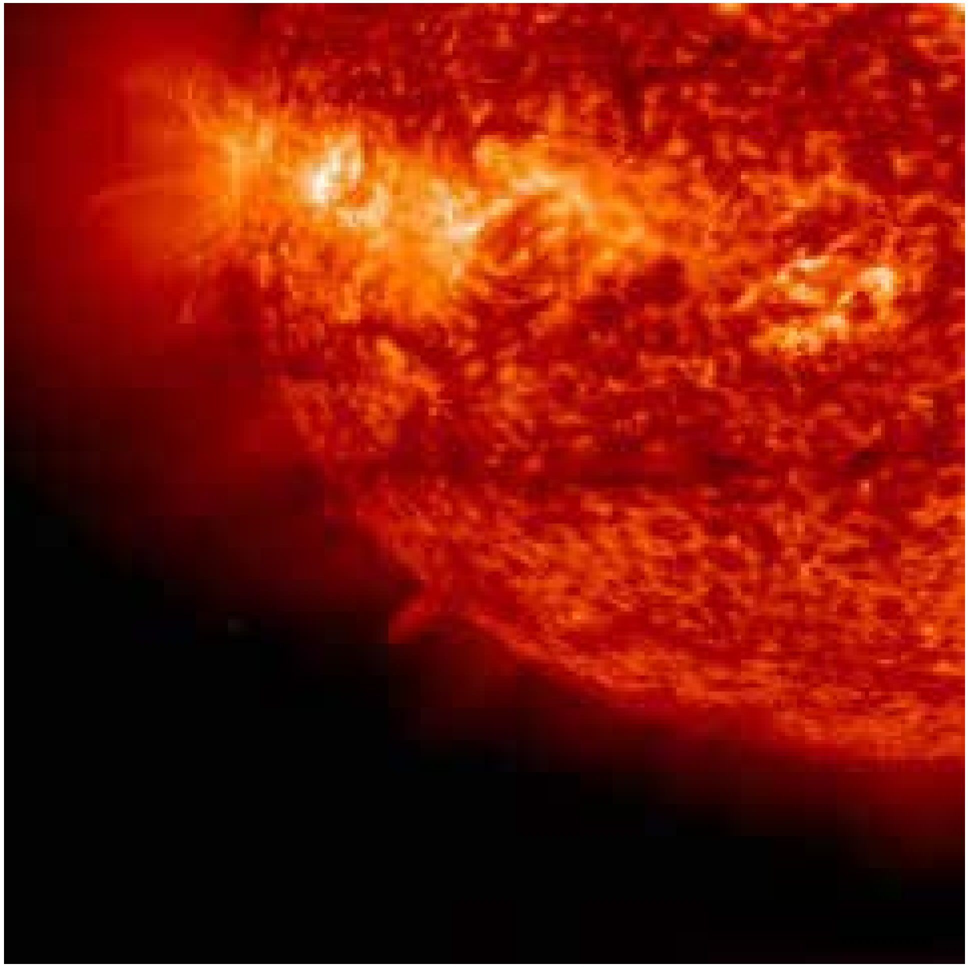
EUV *TRACE team /NASA*

Solar Flare

- Explosive energy release on Sun's surface due to magnetic instabilities
- ejects plasma into space
- can disrupt radio communication on Earth; excite Aurorae Borealis

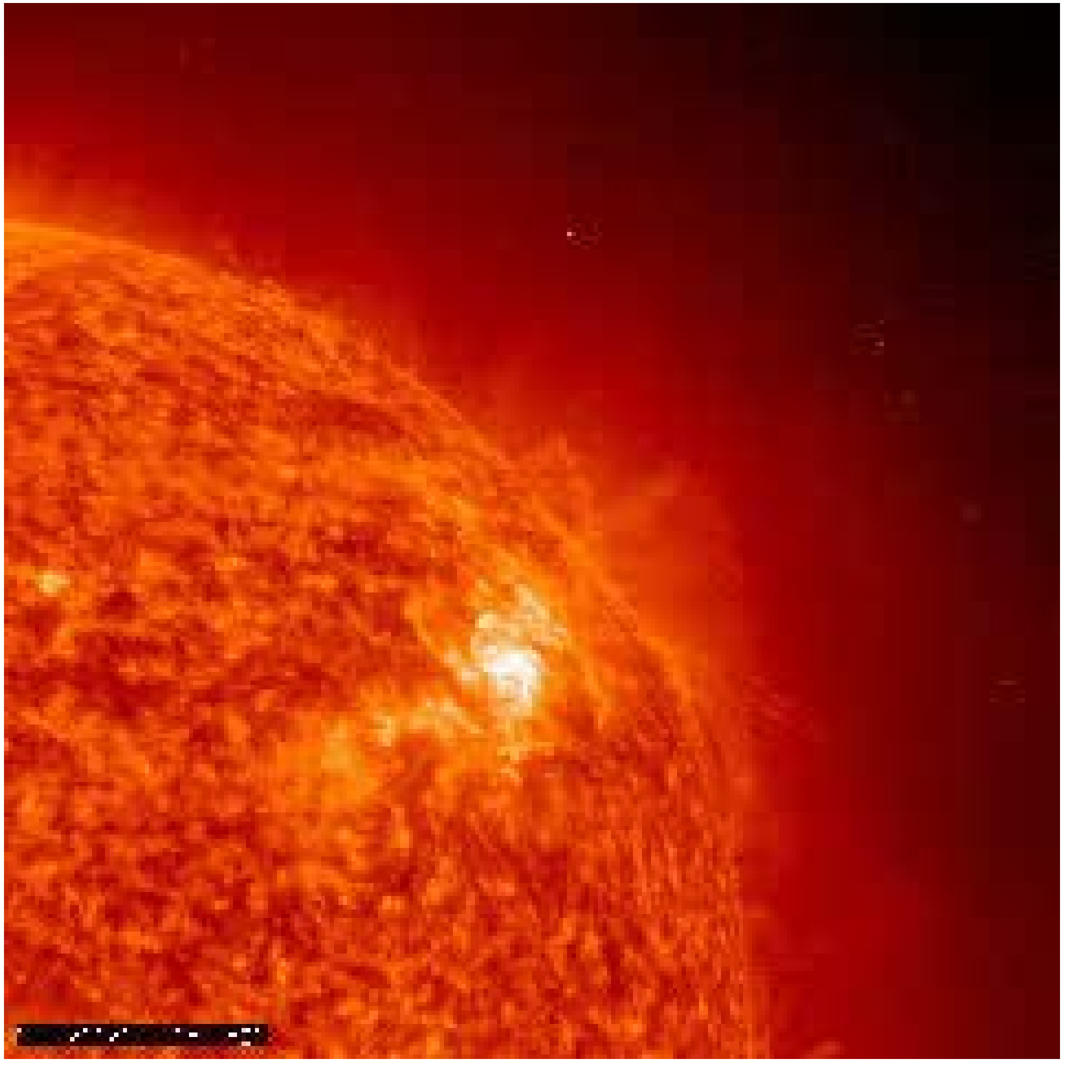


Erupting Solar Flares



http://sohowww.nascom.nasa.gov/

Particle Blast



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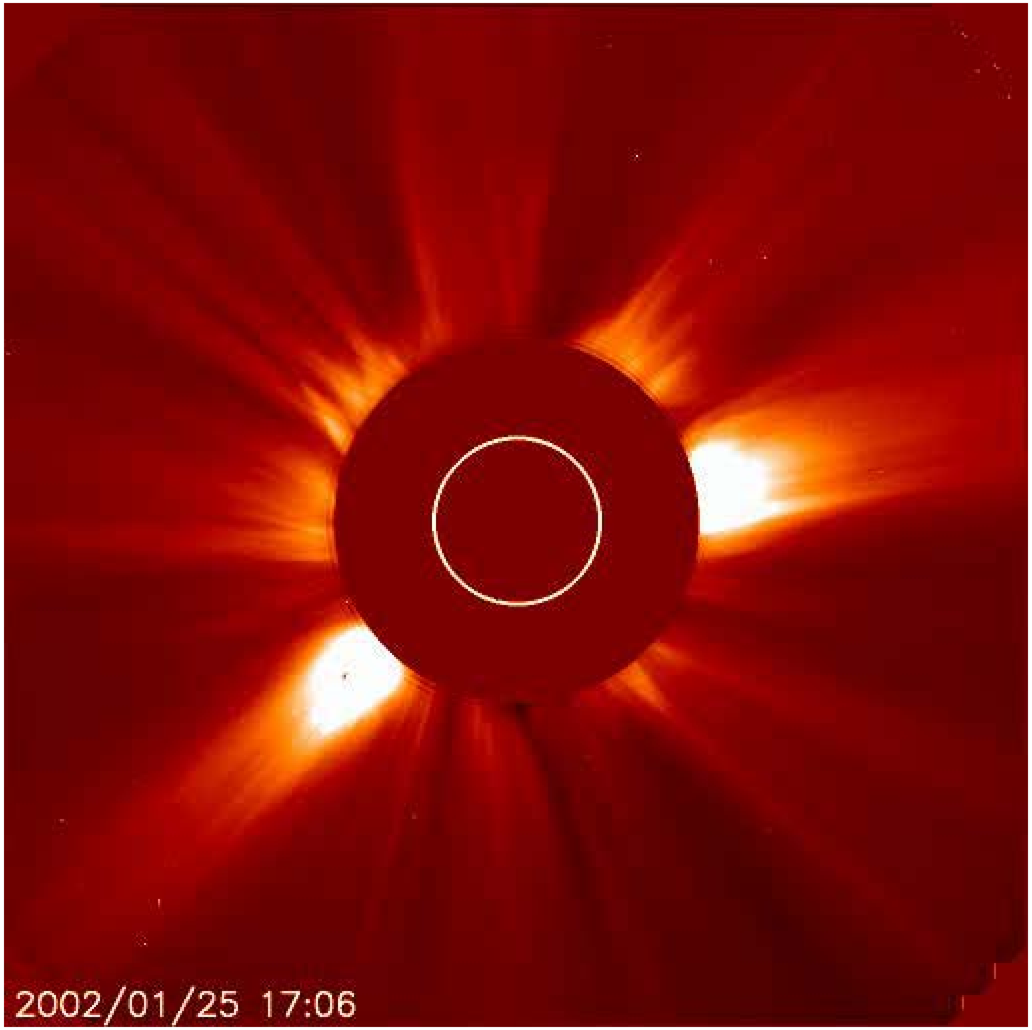
Coronal Mass Ejections



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